

Chapter 17 Navigation in Ice

17-1. Introduction

A vessel navigating in ice must tolerate stresses imposed by an environment that is not encountered by regular shipping. The vessel's form, power, structure, and propulsion system must be designed to withstand these stresses. In addition, the effect of the vessel on the environment must be considered, as well as the effect of the environment on the vessel.

17-2. Environment

In winter a vessel may encounter sheet ice, brash ice, frazil ice, pressurized ice, a pressure ridge, ice with snow cover, or a combination of all these forms. The easiest of these to deal with is sheet ice—homogeneous ice with fairly uniform thickness. A properly designed vessel can travel through sheet ice, up to some limiting thickness that is a function of installed power.

a. Brash ice. The second type of ice, brash, is broken ice that fills a shipping channel with pieces up to 1.8 meters (6 feet) in diameter (Figure 17-1). Brash ice may fill the channel completely or partially and it can be unconsolidated or consolidated and refrozen. This type of ice, because of its lack of homogeneity, restricts vessel movement differently than does sheet ice.



Figure 17-1. Channel filled with brash ice

b. Frazil ice. The third type of ice is frazil ice. Frazil is highly cohesive in its active state. If the water velocity slows beyond a certain point, the frazil crystals can agglomerate and form a mush that can eventually block the channel to a large extent as well as solidify partially.

c. Pressure in the ice. All of these forms of ice can restrict traffic further if the ice sheet is under lateral pressure. Lateral pressure can be caused by wind or water currents. Ice sheets can also push over each other and form a pressure ridge. Such a ridge can grow to extreme depths and virtually block a channel.

d. Snow on the ice cover. The various types of ice described above can also be found with a snow cover. A snow cover does not affect the mechanical properties of the ice to any great extent; however, a snow layer increases the friction between the ice and the ship's hull.

17-3. Vessel Shape

Most vessels are designed to maximize the volume of cargo that they can carry; they tend to be rectangular with minimum curvature of the hull, the extreme example being the rectangular barge. Icebreakers are specifically designed for breaking and clearing ice, and have angled bows, special shapes, and are usually highly powered. Between these extremes are the blunt-bowed ore carriers, the raked-bowed barges, and passenger vessels.

a. Hull resistance factors. The resistance a vessel encounters in ice depends on its hull shape. The efficiency of a particular hull depends on the forces involved in breaking and clearing ice. Basically, a vessel breaks the ice by riding on top of it, causing the ice sheet to fail from tension in the lower and upper layers. After the ship breaks the ice sheet, it must clear the ice fragments from the channel. This is done by pushing the fragments down or to the side. The resistance of the ice to breaking and clearing is a function of the friction between the vessel and the ice and of the lateral pressure in the ice.

b. Variation in hull resistance. The resistance encountered by the vessel increases as the width and length of the vessel increase, as the thickness and strength of the ice increase, as the velocity of the vessel increases, as the friction between the ship and the ice increases, and as the lateral pressure in the ice increases.

c. Barge-hull resistance. In the case of a tug and towed or tug-pushed barges, the shape of the forward part of the hull has the largest effect on the resistance. A wide vessel with a plumb, blunt bow that has a very rough surface will encounter extreme resistance. If the bow is so blunt that the ice cannot pass to the side or below the vessel, the ice will pile up in front of the vessel, forming its own "bow" shape, and will eventually cause such high resistance that the vessel will be unable to move.

17-4. Auxiliary Icebreaking Devices

Several different methods have been developed to facilitate icebreaking and ice navigation. The most promising methods are:

- Low-friction hull coating
- Hull bubbler systems

- Air-cushion vehicles
- Auxiliary icebreaking devices.

These systems have been developed and refined by the U.S. Army Corps of Engineers, U.S. Coast Guard, Canadian Coast Guard, and ice researchers, as well as in Finland and Russia.

a. Surface friction. Figure 17-2 shows the coefficient of friction of various coatings, as well as that of steel on ice. The polyurethane and epoxy (nonsolvented coatings) proved to be the most effective in friction reduction and coating endurance.

b. Hull bubbler systems. Hull bubbler systems have been installed on several European icebreakers and on the latest USCG small lake icebreakers. Bubbler systems work by interposing air and water between the ice and the hull of the vessel. Figure 17-3a is a schematic of the bubbler system. Figure 17-3b depicts its deployment on a USCG icebreaker. Figure 17-4 shows the results of full-scale tests of the bubbler system on a European icebreaking ferry.

c. Air-cushion vehicles. The air-cushion vehicle (ACV) is the most dramatic contribution of modern technology to icebreaking. The vehicles can skim over the ice and break it at speeds of 5 to 32 km/hr (3 to 20 mph). The icebreaking occurs both at low speeds of advance as shown in Figure 17-5 (top) and at higher speeds of advance (bottom). At high speeds, the critical speed of the craft deflects the ice sheet to the icebreaking point. At low speeds, the air cushion extends under the ice, displacing the supporting water. Deprived of its support, the ice sheet fails under the pressure of the air cushion. Tables 17-1 and 17-2 show the results of tests conducted by the Canadian Coast Guard on ACV's. These tests indicate that an ACV can break ice whose thickness is 90 percent of the cushion pressure expressed in inches of water. The ACV has significant potential for aiding ice-jam flood control in shallow rivers and estuaries where vessel draft is limited. An ACV placed in front of a conventional icebreaker will increase its effectiveness.

d. Auxiliary icebreaking devices. A device that has been used in Russia and has been evaluated in the U.S. is the ice cutting vehicle. Such a vehicle cuts the ice with some apparatus such as a circular saw or a high-pressure water jet. The weakened ice is then either conveyed up onto the vehicle and thrown over the side, or deflected beneath and to the side of the vehicle by underwater ice guides. Figure 17-6 depicts conceptual sketches of two possible ice cutting and clearing devices. These devices could be used to keep channels in narrow rivers between locks and dams clear of ice. Another device is the icebreaking prow, which is attached to a conventional towboat in the same manner as a barge (Tatinclaux and Martinson 1988). Vanes fastened to the front and bottom of the prow break the ice and guide the ice pieces underneath and to the sides of the prow, where the ice accumulates under the adjacent ice cover. The opened channel behind the vessel/prow combination is left largely ice-free.

17-5. Summary

Vessels operating in ice must be given special consideration if they are to operate safely and efficiently. The vessel must have the power and structure to overcome the resistance and loads imposed by the ice environment.

a. Unassisted icebreaking. Properly shaped vessels with adequate power can break the sheet ice that is encountered on lakes and rivers. The primary problem is not so much sheet ice but brash and frazil ice that can fill the channel and cause unusually high resistance because of the friction between the ice and hull surface. This problem can be mitigated somewhat by a low-friction, high-wear coating.

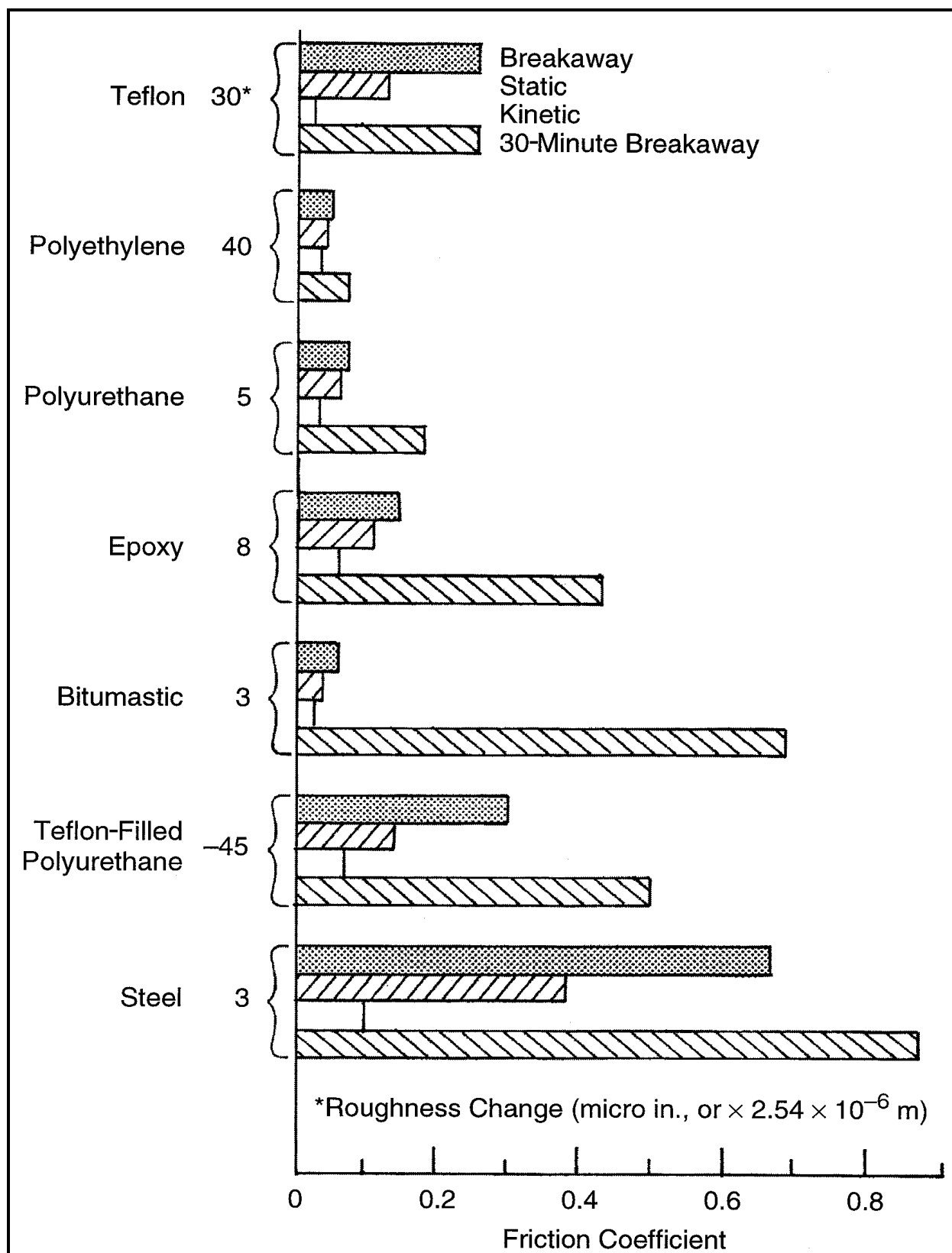
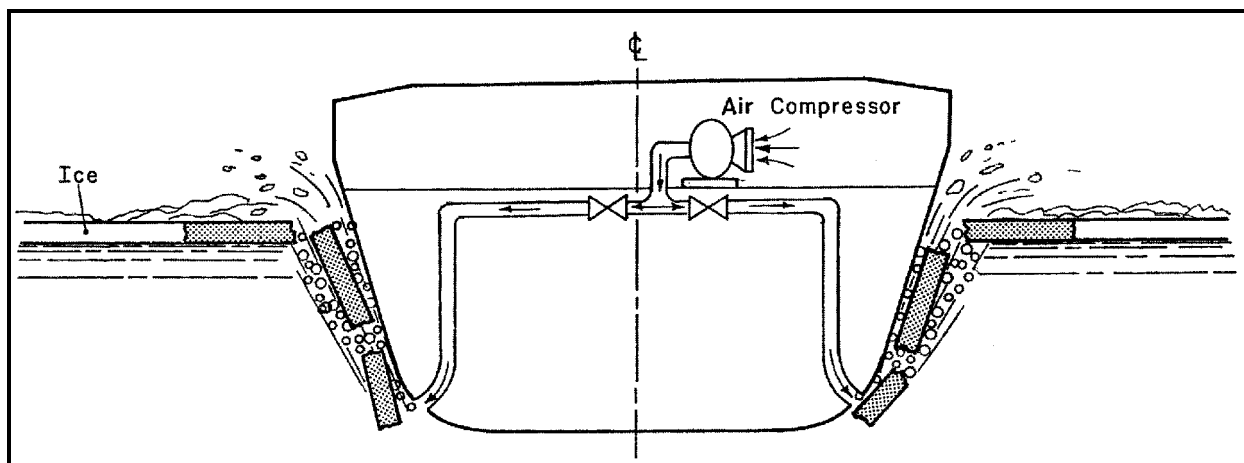
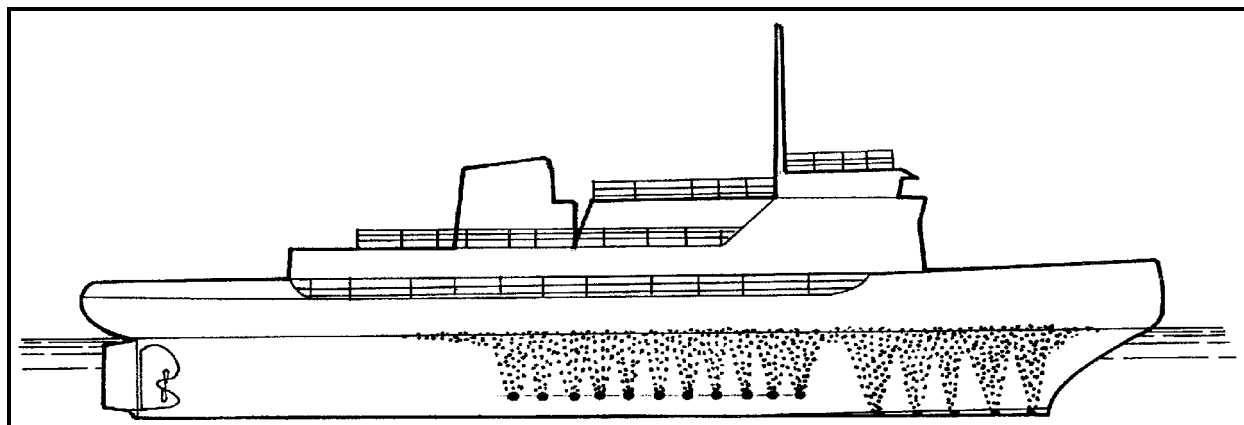


Figure 17-2. Coefficient of friction for steel and various hull surfaces on ice



a. Schematic



b. Bubbler installed on icebreaker

Figure 17-3. Hull air-bubbling system

Table 17-1
Air-cushion Vehicles Used in Trials and Operations

| Vehicle | Gross Length m (ft) | Beam m (ft) | Vehicle Weight kg (lb) | Cushion Pressure kPa (in.) of H ₂ O |
|----------|------------------------|----------------|---------------------------|---|
| ACT-100 | 22.5 (73.8) | 17.1 (56.1) | 260,800 (575,000) | 6.90 (27.7) |
| H-119 | 13.2 (43.3) | 6.0 (19.7) | 24,000 (53,000) | 4.86 (19.5) |
| HJ-15 | 12.1 (39.8) | 5.4 (17.7) | 19,400 (42,700) | 3.74 (15.0) |
| Voyageur | 19.8 (65.0) | 10.4 (34.0) | 40,500 (89,300) | 2.62 (10.5) |
| AC-80 | 6.0 (19.7) | 3.5 (11.5) | 1,300 (2,900) | 1.0 (4.0) |

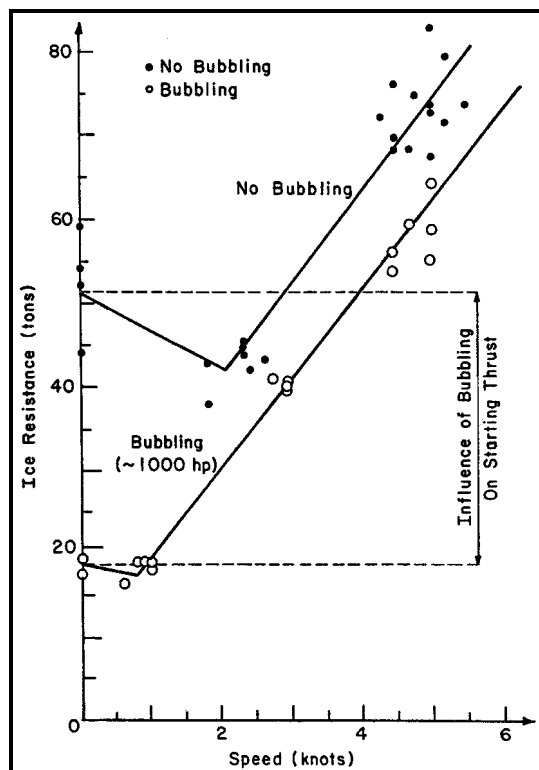


Figure 17-4. Air bubbler tests on a European icebreaking ferry

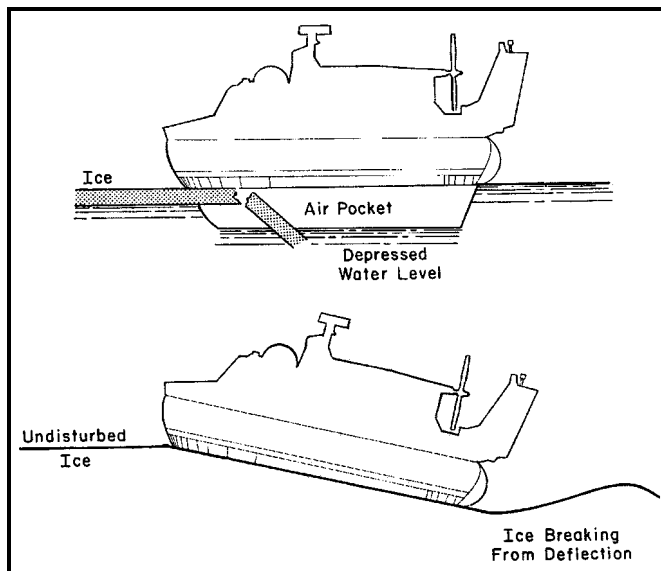


Figure 17-5. Air-cushion vehicle. Top: Low speed icebreaking. Bottom: High speed icebreaking

Table 17-2
Air-Cushion Vehicle Icebreaking Data

| Vehicle | Date and Location | Ice Thickness, cm (in.) | Cushion Pressure kPa (in.) of H ₂ O | Speed km/h (mph) |
|----------|--------------------|-------------------------|---|------------------|
| ACT-100 | 1971 - YK | 69 (27) | 6.92 (27.8) | 6-8 (4-5) |
| ACT-100 | 1972 - Tuk | 51-56 (20-22) | 6.23 (25.0) | 6-11 (4-7) |
| H-119 | 1973 - Montreal | 23 (9) | 4.01 (16.1) | 2-6 (1-4) |
| H-119 | 1974 - Toronto | 23-25 (9-10) | 2.64 (10.6) | 6-10 (4-6) |
| HJ-15 | 1974 - Toronto | 23-25 (9-10) | 2.91 (11.7) | 6-10 (4-6) |
| Voyageur | 1974 - Parry Sound | 23-25 (9-10) | 2.49 (10.0) | 8-11 (5-7) |
| Voyageur | 1974 - Parry Sound | 46-51 (18-20) | 2.49 (10.0) | 19-29 (12-18) |
| Voyageur | 1975 - Montreal | up to 76 (up to 30) | 2.0-2.5 (8-10) | 19-50 (12-31) |
| Voyageur | 1976 - Montreal | up to 102 (up to 40) | 2.0-2.5 (8-10) | 19-50 (12-31) |
| ACT-100 | 1976 - Thunder Bay | 38-41 (15-16) | 5.0 (20) | 16 (10) |
| AC-80 | 1976 - Ottawa | 20 (8) | 1 (4) | 8-10 (5-6) |

b. Cooperative programs. To enhance winter navigation on lakes and rivers, additional assistance is often required in the form of icebreaking, ice clearing, ice control, and towing or kedging. This assistance usually is provided by self-help programs of private industry. In certain limited cases, assistance is also provided by government agencies (principally the U.S. Army Corps of Engineers and U.S. Coast Guard).

17-6. References

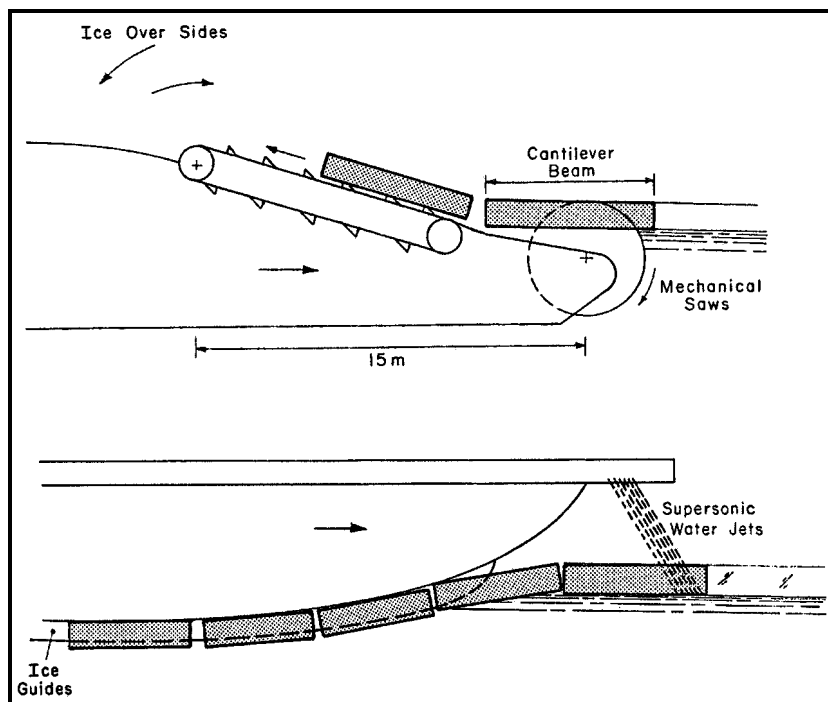
a. Required publications.

None.

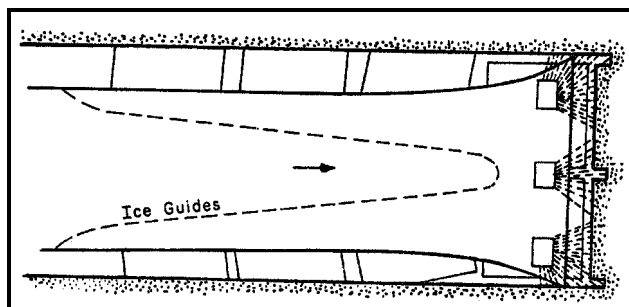
b. Related publications.

Tatinclaux and Martinson 1988

Tatinclaux, J.-C., and C. Martinson. 1988. *Development of a River Ice Prow*, CRREL Report 88-9, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.



a. Type 1



b. Type 2

Figure 17-6. Ice cutter